REPORT DOCUMENTATION PAGE

AFRL-SR-AR-TR-04-

0151

1. REPORT DATE *(DD-MM-YYYY)*

2. REPORT TYPE
Final

3. DATES COVERED *(From - To)*
1 Jun 02 - 31 Aug 03

4. TITLE AND SUBTITLE
Multi-Vehicle Experimental Platform for Distributed Coordination and Control

5a. CONTRACT NUMBER

5b. GRANT NUMBER
F49620-02-1-0216

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Jonathan P. How

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Department of Aeronautics and Astronautics
Massachusetts Institute of Technology
77 Massachusetts Ave
Cambridge, MA 02319

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

AFOSR/NM
4015 Wilson Blvd., Room 713
Arlington, VA 22203-1954

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for Public Release; Distribution Unlimited

20040315 024

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report discusses the two testbeds that were developed with the DURIP grant, showing that all of the objectives were met and that they provide excellent facilities for demonstrating advanced coordination and control concepts in real-time, in realistic environments. Performinf experiments on these testbeds will highlight the fundamental challenges associated with: (i) planning for a large team in real-time; (ii) developing controllers that are robust to uncertainty in the situational awareness, and are sufficiently flexible to respond to dynamic changes; and (iii) using communication networks and distributed processing to develop integrated and cooperative plans.The testbeds have been used to support several research and educational projects at MIT:
1. AFOSR Cooperative Control Theme
2. DARPA Mixed-Initiative Control of Automa-teams (MICA)
3. DARPA Software Enabled Control (SEC)
4. MIT Senior Capstone design class (16.821 Flight Vehicle Development)
Proposals have been submitted to the DoD ACO and DARPA HURT programs that will use the testbeds.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Dr. Jonathan P. How
					19b. TELEPHONE NUMBER *(Include area code)* 617-252-1536

Multi-vehicle Experimental Platform for Distributed Coordination and Control

Short Title: DURIP Multi-vehicle Testbed

DURIP Award F49620-02-1-0216
Period of Performance: 5/1/02 - 8/31/03

PI Dr. Jonathan P. How
Massachusetts Institute of Technology
Department of Aeronautics & Astronautics
Bldg. 33 Room 328, 77 Massachusetts Avenue
Cambridge, MA 02139-4307
617-253-3267 (phone)
617-253-7397 (fax)
jhow@mit.edu

Jonathan How
Jonathan P. How

AFOSR Technical Officer: Lt Col Sharon Heise, USAF, PhD
Program Manager, Dynamics & Control
AFOSR/NM
4015 Wilson Blvd, Rm 713
Arlington, VA 22203
voice: 703-696-7796
fax: 703-696-8450

Multi-vehicle Experimental Platform for Distributed Coordination and Control

Jonathan P. How (PI)
Department of Aeronautics and Astronautics
Massachusetts Institute of Technology
DURIP Award F49620-02-1-0216 (5/1/02 - 8/31/03)

Overview

The objective of this proposal was to build a multi-vehicle testbed to demonstrate and evaluate the coordination and control approaches under development at MIT as part of several ongoing DoD funded research programs. This work was motivated by the observation that a key step towards transitioning these high-level algorithms to future missions will be to successfully demonstrate that they can handle similar challenges on scaled vehicles operating in realistic environments.

Two unique testbeds have been developed at MIT to perform these demonstrations. The testbeds have been designed to reflect the complexity expected in future combat operations and are comprised of many (semi-) autonomous, heterogeneous vehicles. We used *simple* vehicles (UAVs,blimps, rovers) so that *many* of them could be "flown" together. This provides a good combination of flexibility, agility, and mobility, and allows us to use the testbed in a broad range of applications. Of particular significance is the goal of having many of these vehicles working in coordinated fashion to provide surveillance, detection, assessment, and tracking of multiple moving targets.

This report discusses the two testbeds that were developed with the DURIP grant, showing that all of the objectives were met and that they provide excellent facilities for demonstrating advanced coordination and control concepts in real-time, in realistic environments. Performing experiments on these testbeds will highlight the fundamental challenges associated with: (i) planning for a large team in real-time; (ii) developing controllers that are robust to uncertainty in the situational awareness, and are sufficiently flexible to respond to dynamic changes; and (iii) using communication networks and distributed processing to develop integrated and cooperative plans.

The testbeds have been used to support several research and educational projects at MIT:

- AFOSR Cooperative Control Theme
- DARPA Mixed-Initiative Control of Automa–teams (MICA)
- DARPA Software Enabled Control (SEC)
- MIT Senior Capstone design class (16.821 Flight Vehicle Development)

Proposals have been submitted to the DoD ACO and DARPA HURT programs that will use the testbeds.

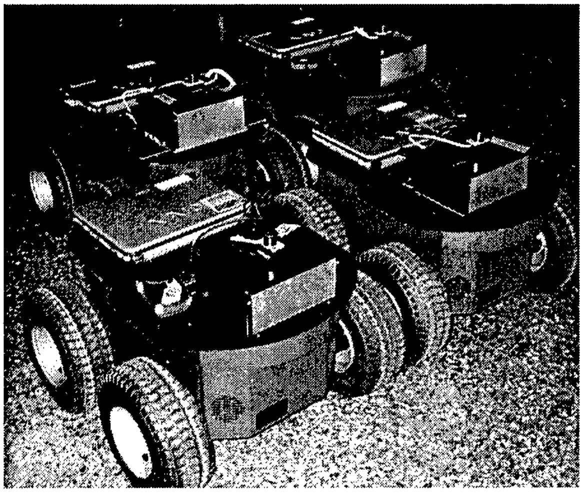

Fig. 1: 4 of 8 rovers.

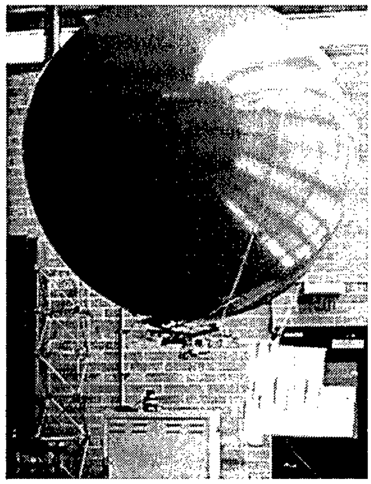

Fig. 2: 1 of 4 blimps.

Testbed Description

This testbed has been designed to simulate many challenging operational scenarios that are of direct interest to the AFOSR. The specific focus is in the area of *cooperative coordination and control of multiple vehicles* for missions such as:

1. Low-cost multi-target surveillance and tracking
2. Wide-spread search missions
3. Suppression of enemy air defenses (SEAD)
4. Moving target location and tracking

These missions typically require the close coordination and control of many different types of vehicles (*e.g.*, manned vehicles {fighters, strike, and electronic suppression}, semi-autonomous UAVs {fixed-wing and helicopters}, surveillance aircraft and satellites, communication vehicles {AWACS}, and ground forces) to accomplish the overall objectives. Two unique testbeds have been developed at MIT to analyze the performance of the high-level planning algorithms for these types of missions. One uses multiple rovers and blimps operated indoors to emulate a heterogeneous fleet of vehicles performing a search and rescue mission. The second uses eight UAVs that are flown autonomously using a commercially available autopilot from Cloud Cap Technology.

Rover/Blimp Testbed - The first testbed uses multiple (8) rovers and blimps (4) operated indoors to emulate a heterogeneous fleet of vehicles that could be used to perform SEAD type missions. The rovers in Fig. 1 are ActivMedias P3-ATs. A Sony VAIO mounted on each rover processes sensor data and performs the low-level control. All high-level planning is done off-board using laptops running MATLAB, AMPL, and CPLEX, but with a direct wireless Ethernet connection, this is essentially the same as having both laptops onboard.

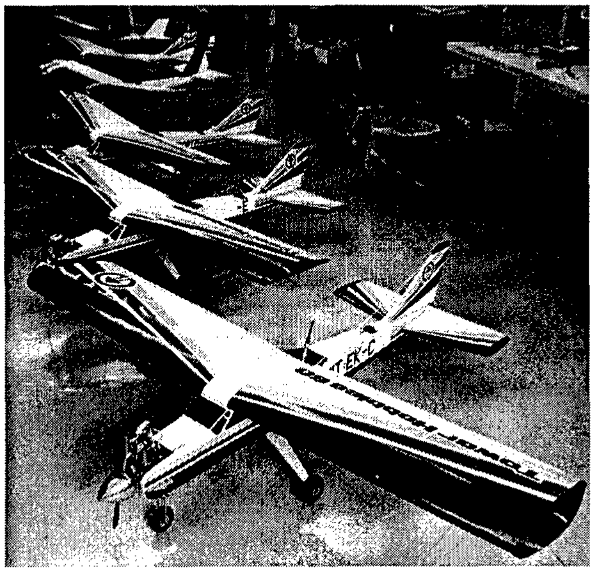

Fig. 3: 6 of 8 UAVs.

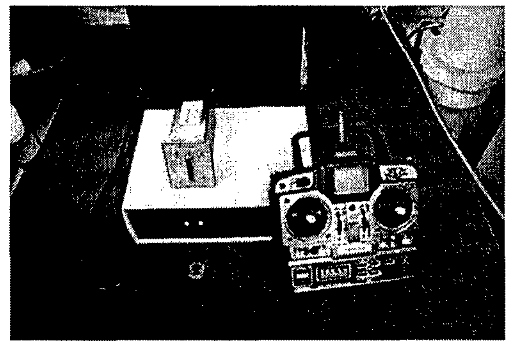

Fig. 4: Groundstation, Avionics and and pilot console for Cloud Cap system.

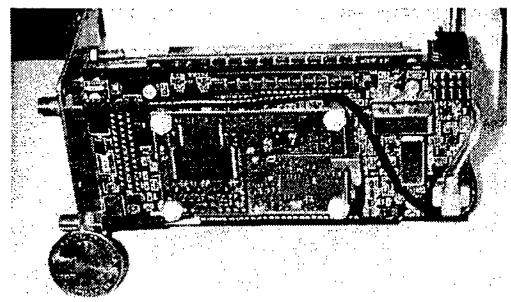

Fig. 5: Cloud Cap Piccolo autopilot.

The ArcSecond Constellation 3D-i laser metrology system is used to measure the vehicle position indoors[1]. This has been verified to give 4mm position accuracy at 20Hz. The twelve channel receiver provides both raw Code phase and carrier phase measurements for all tracked satellites. The 7ft diameter blimps in Fig. 2 were scaled to carry the VAIO and will have an identical control architecture. The indoor tests can be performed at the MIT Johnson Athletic Center which has a room with dimensions 65×125×25 ft. The rovers can also be outfitted with the Canadian Marconi Company Superstar^{TM} receiver for outdoor operations.

The video cameras on the rovers are four Axis EVI-D30 with remote controlled pan tilt and object tracking capabilities. Each camera outputs analog video to an Axis 2401 video server which converts the signal into digital video and transmits it over Ethernet to a wireless bridge. This digital video is then transmitted to the ground station, which can show the four videos at the same time. Additionally, the pan/tilt and object tracking capabilities of the cameras can be exploited remotely from the ground station.

UAV Testbed - 8 UAVs have been built to provide a platform for flight testing and evaluation of the coordination and control algorithms (Fig. 3). Small aircraft (RC-sized trainers) were purposefully chosen to reduce operational complexity while still providing a high degree of flexibility in the missions that can be performed. Only slight modifications are required to increase the payload and endurance requirements (3 lbs., 20 mins respectively) for a SEAD

[1]See White paper 063102, "Constellation 3Di Error Budget and Specifications," Copyright 2002, Arc Second, Inc. Dulles, VA {www.arcsecond.com}

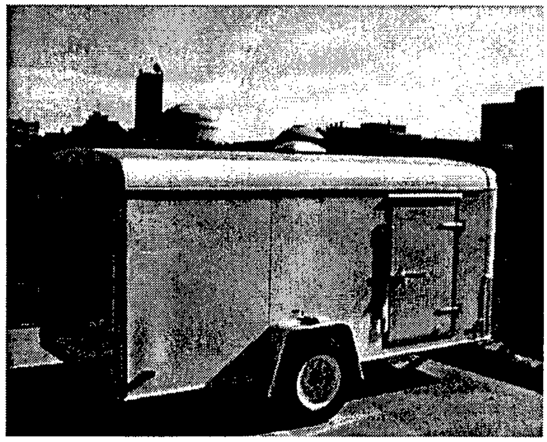

Fig. 6: Trailer used to store and transport the UAVs.

type mission demonstration. Fig. 3 shows several of the modified Tower Trainer planes in the fleet. The Piccolo^{TM} autopilot from Cloud Cap (Fig. 5) is used onboard the aircraft to perform the autonomous waypoint navigation and vehicle stabilization, primarily using GPS, IMU and air data measurements[2]. One Watt transmission of data over the 912 MHz band permits the vehicles to navigate up to three miles from the ground station (Fig. 4) and new plans can be continuously uploaded to the vehicles through this channel.

A wireless video system has been integrated with the UAV testbed to produce high quality images from the airborne vehicles Fig. 8 shows a typical aerial shot from one of the UAVs. This system is used to verify the position of the vehicles and provide user feedback for high level decision making. We have recently negotiated a deal to fly the UAV testbed at the Crow Island Airfield in Maynard, MA (see Figs. 7 and 8), but have also discussed with Robert Murphey the possibility of doing more extensive testing at Eglin AFB. The trailer purchased to store and move the UAVs and rovers is shown in Figure 6.

The autopilots can also be tested on the ground using the hardware in the loop simulation environment shown in Figure 9. The figure shows the autopilots (top right) being stimulated by separate CPUs. The data is then passed to the ground station (other side of the laboratory) using the 912 MHz link, where it is displayed to the operator of the UAV team (bottom) and passed onto the planning processors (separate bank of CPUs top left). A 3 GHz Dell desktop computer with 2 large monitors serves as the operator ground station for all of the testbeds. From this location all of the vehicles and planning algorithms can be monitored through an integrated GUI which allows the creation of mission scenarios and dynamic changes to the state of the world (*e.g.*, avoidance regions, targets).

Planning Computers and Wireless Network – The 12 Dell planning laptops (top left of Figure 9) are connected together on a 100 Mbps Ethernet (the wired network). A wireless

[2]www.cloudcaptech.com

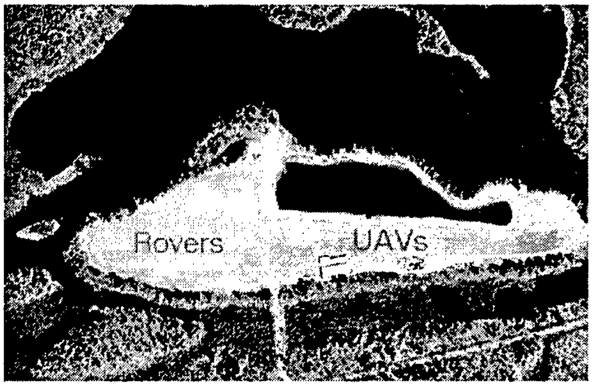

Fig. 7: Local flying field at Crow Island. Island is approximately 2000ft long. Main runway for UAVs to the right, which leaves a very large area to the left to use for the rovers.

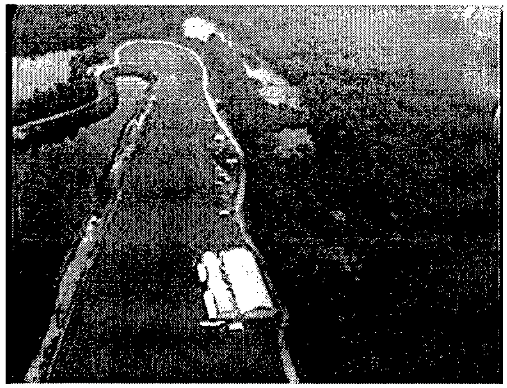

Fig. 8: Overhead of the local flying field at Crow Island taken with the onboard camera.

Ethernet access point is also attached to this network which connects the Dells with the VAIOs on the rovers (802.11b wireless Ethernet network at 11 Mbps). The access point is a Linksys WAP11 with a WSB24 signal booster to increase range and reliability of the network. The VAIOs use their internal wireless network cards. All of the main pieces of software (controller, MATLAB) use TCP/IP to communicate, which is easy to use and maintain. The Dell computers are also equipped with a 10-seat license for CPLEX V8.0 which is used by the high-level planning algorithms.

Additionally, there is a second wireless network at 54 Mbps based on the 802.11g standard that connects the base station to four video cameras in the rovers. The components of this network are: a Netgear WG602 Access Point also connected to the 100 Mbps wired Ethernet, and four Netgear WG101 wireless bridges on the rovers. These bridges are connected to the digital video servers through Ethernet cable. The range and reliability of the network is increased by attaching a 18 dBi Netgear patch panel gain antenna to the access point, and four 5 dBi Netgear omnidirectional antennas attached to the wireless bridges. The high bandwidth of this network is ideal for transmitting digital video. By using a different wireless channel, this network works independently of the network that connects the VAIOs. This ensures that the high volume of digital video never interferes with the more sensitive connections used to control the rovers. There are also four SRM6000 (Data-Linc Group) radio modems for longer range communications ($\approx$5km).

Control Architecture – Figure 10 shows the control architecture used for the UAVs, but the setup is very similar for the rovers and blimps. Low-level control and the basic estimation tasks are run onboard, and the planning for the vehicles is done off-board. The *planner* outputs dynamically feasible waypoint lists and actions (*i.e.,* classify, strike, assess) to the vehicles, and monitors the uncertain states of the vehicles and the situational awareness. When significant changes to the situational awareness are detected, the cost map is then updated, the tasks are re-assigned and/or the trajectories are redesigned.

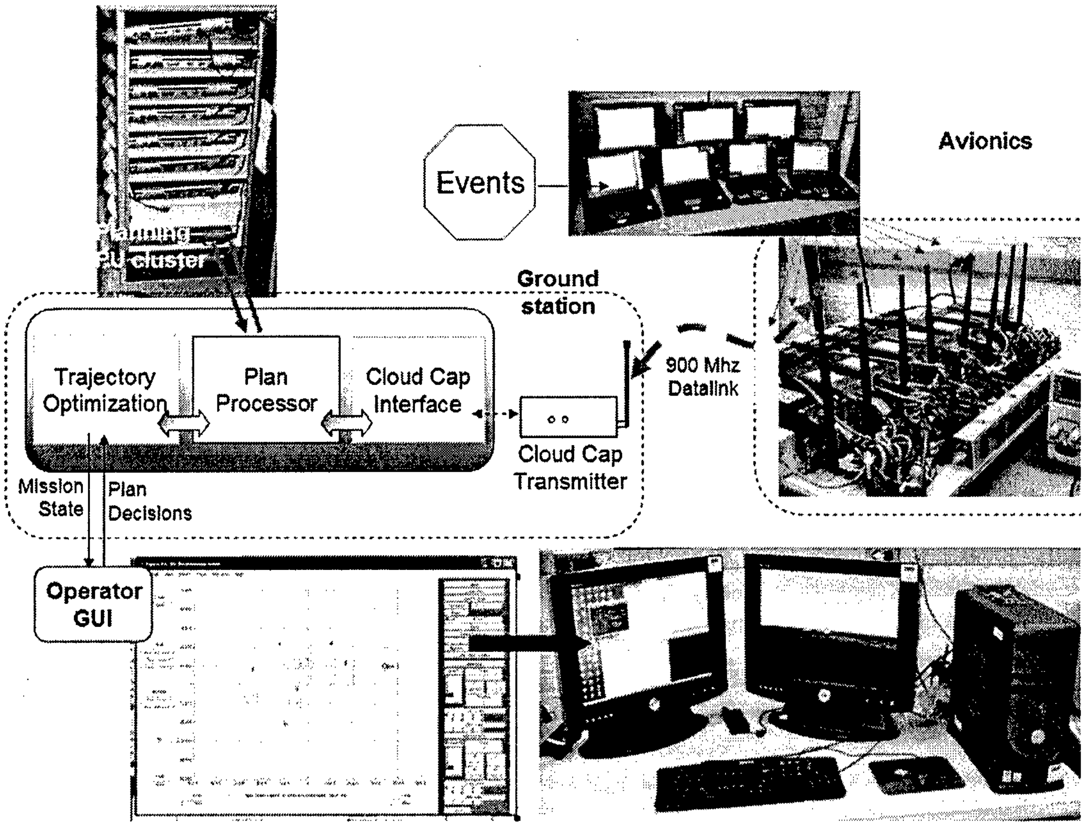

Fig. 9: Hardware in the loop configuration for the UAV testbed. Multiple autopilots (top right) are independently run by simulation software to simulate in-flight demonstrations of the coordination algorithms.

Note that the system infrastructure was set up to allow us to simulate a fully integrated fleet of UAVs – all data passes through a central hub that performs data management between the planning computers and vehicles, effectively simulating communication delays, vehicle sensors and uncertainty in the environment. Using this setup greatly simplifies the testbed, while maintaining nearly all of the functionality of a fully integrated system. For example, as shown in Figures 11 and 12, we can use our testbed to investigate the impact of communication networking issues on the coordination problem by imposing various limitations/constraints on how the planning laptops communicate (using their own wireless or Ethernet links). Future work will demonstrate the effectiveness of various control architectures on the task assignment process, as would be seen in utilizing dynamic sub-teams of various compositions.

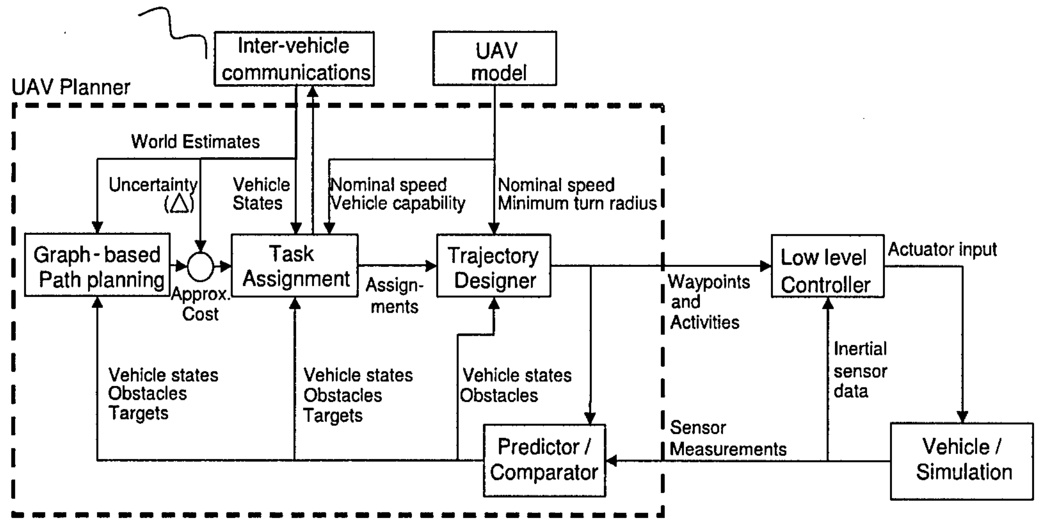

Figure 10: System algorithm architecture for rover, blimp and UAV testbeds.

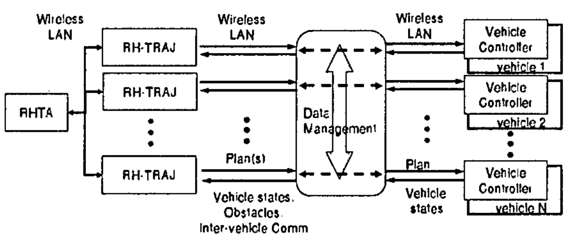

Fig. 11: Control architecture: Decentralized path planning/Centralized task assignment.

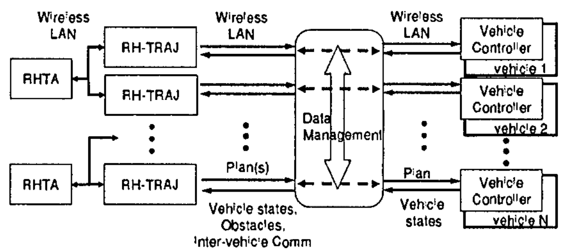

Fig. 12: Control architecture: Decentralized path planning/Distributed task assignment.

Results

Typical results from experiments already performed on these two testbeds are shown in Figs. 13 and 14. Fig. 13 shows indoor results using rovers with dynamics constrained so that they emulate UAVs (the vehicles move at a constant speed with a limited turn radius). The four rovers are tasked to execute a SEAD mission in an environment with one centrally located avoidance region and a removable SAM site. They are divided into two sub-teams of strike and bomb damage assessment (BDA) vehicles, and each is assigned two targets. This experiment demonstrated the ability to dynamically reassign tasks when one of the BDA vehicles (Rover 1) is stopped before completing all of its tasks and the second BDA member has to finish the mission. Many multi-UAV simulations have also been performed with the hardware-in-the-loop autopilot simulators (Fig. 9) and the UAVs have been operated

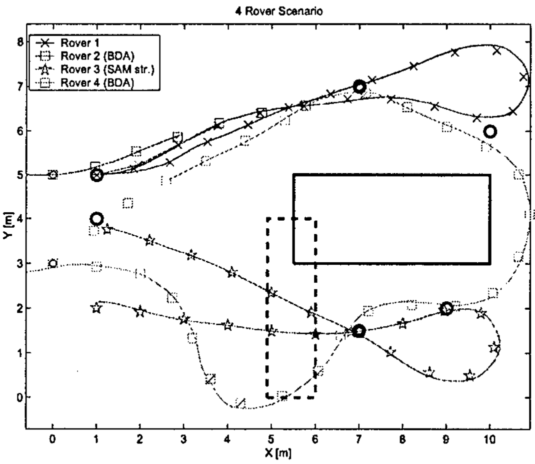

Fig. 13: Four rover experimental data from a typical SEAD mission.

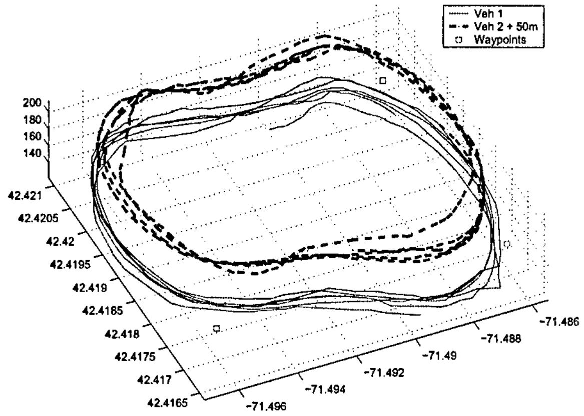

Fig. 14: Data from 2 UAVs flying simultaneously.

autonomously on numerous occasions. Fig. 14 shows recent results with two of the UAVs simultaneously flying the same waypoints (note that the vertical offset was added intentionally). By varying the commanded speed we were able to execute a fairly tight formation flying maneuver with the two vehicles.

More recent results are included in the following references:

1. A. G. Richards, Y. Kuwata, and J. P. How, "Experimental Demonstrations of Real-Time MILP Control, Proceedings of the AIAA *Guidance, Navigation, and Control Conference*, August 2003, (AIAA Paper 2003-5802).
2. E. King, M. Alighanbari, Y. Kuwata, and J. How, "Coordination and Control Experiments on a Multi-vehicle Testbed, to appear at the IEEE *American Control Conference,* 2004.
3. Ellis King, Mehdi Alighanbari, and Jonathan How, "Experimental Demonstration Of Coordinated Control For Multi-Vehicle Teams, to appear at the *16th IFAC Symposium on Automatic Control in Aerospace,* June 2004.
4. L. Bertuccelli, M. Alighanbari, J. How, "Robust planning for coupled, cooperative UAV missions," submitted to the IEEE *CDC*, 2004.
5. E. King, Y. Kuwata, M. Alighanbari, and J. How, "Coordination And Control Experiments for UAV Teams," presented at the *27th Annual AAS Guidance and Control Conference*, Breckenridge, Colorado, February 4–8, 2004 (04-014).

And theses:

1. C. Sae-Hau *Avionics and Software for a Distributed Multi-rover Testbed*, EE, MIT, Aug. 2004

2. Yoshiaki Kuwata, *Real-time Trajectory Design for Unmanned Aerial Vehicles using Receding Horizon Control*, S.M. Thesis, Dept. of Aeronautics and Astronautics, MIT, June 2003.
3. Ellis King, *Demonstration of Distributed Coordination and Control on a multi-UAV Testbed*, S.M. Thesis, Dept. of Aeronautics and Astronautics, MIT, expected May 2004.
4. L. Bertuccelli, *Cooperative Mapping Algorithms for a Fleet of UAVs*, S.M. Thesis, Dept. of Aeronautics and Astronautics, MIT, expected June 2004.

Summary

As these multi-vehicle testbeds mature, we will be able to demonstrate more sophisticated experiments such as:

- Multi-vehicle execution of a representative SEAD mission which includes dynamic teaming/tasking, coordination of recon/strike/BDA tasks and execution despite imperfect information about the world and/or other team members.
- Coordination of multiple heterogeneous vehicles Both autonomous air and ground vehicles will be used in conjunction to demonstrate the use of multiple vehicle systems with different capabilities. For example, the blimps were designed to perform reconnaissance and classification tasks in conjunction with the rovers that act as strike vehicles. And the UAVs can be used to map the environment for the rovers.
- Constrained network/communications Demonstrations of system performance using imperfect information and limited communication between vehicles. This experiment will provide a realistic demonstration of the performance of a team of UAVs operating under limited communications/information constraints. Depending on the scenario used, these constraints can be imposed artificially or would occur naturally due to the extensive range between vehicles.

Our experience has shown that experiments on real vehicles are very stressing for these planning algorithms and repeated successful experimental demonstrations of these algorithms will be a significant milestone for the cooperative control theme.

AFOSR DURIP
Grant No. F49620-02-1-0216
Identification of Acquired Equipment

Location	Standard Name	Model	Serial #	Manufacturer	Supplier	Acq Doc #	Acq Date	Amount
41-105	CONTROLLER	MP2000	01-301	MICROPILOT	MICROPILOT	4500407531	6/10/2002	$10,347.00
41-105	COMPUTER	PICCOLO EVAL KIT	19	CLOUD CAP TECH	CLOUD CAP	4500430280	10/7/2002	$12,572.00
41-105	COMPUTER, LAPTOP	VAIO SRX99	3301309	SONY	GOVCONNECTION	4500463000	11/27/2002	$1,607.00
41-105	COMPUTER, LAPTOP	VAIO SRX99	3301312	SONY	GOVCONNECTION	4500463000	11/27/2002	$1,607.00
41-105	COMPUTER, LAPTOP	VAIO SRX99	3400189	SONY	CHICAGO COMPUTER	4500478348	2/7/2003	$1,671.00
41-105	COMPUTER, LAPTOP	VAIO SRX99	3402893	SONY	CHICAGO COMPUTER	4500478348	2/7/2003	$1,672.00
41-105	COMPUTER, LAPTOP	VAIO SRX99	3403798	SONY	CHICAGO COMPUTER	4500478348	2/7/2003	$1,671.00
41-105	COMPUTER, LAPTOP	VAIO SRX99	3404729	SONY	CHICAGO COMPUTER	4500478348	2/7/2003	$1,672.00
41-105	COMPUTER, LAPTOP	VAIO SRX99	3405217	SONY	CHICAGO COMPUTER	4500478348	2/7/2003	$1,671.00
41-105	COMPUTER, LAPTOP	VAIO SRX99	3405303	SONY	CHICAGO COMPUTER	4500478348	2/7/2003	$1,672.00
41-105	COMPUTER, LAPTOP	VAIO SRX99	3401012	SONY	CHICAGO COMPUTER SUPPLY	4500489457	3/18/2003	$1,674.00
41-105	COMPUTER, LAPTOP	VAIO SRX99	3401639	SONY	CHICAGO COMPUTER SUPPLY	4500489457	3/18/2003	$1,673.00
41-105	COMPUTER, LAPTOP	VAIO SRX99	3402924	SONY	CHICAGO COMPUTER SUPPLY	4500489457	3/18/2003	$1,673.00
41-105	COMPUTER, LAPTOP	VAIO SRX99	3404151	SONY	CHICAGO COMPUTER SUPPLY	4500489457	3/18/2003	$1,674.00
41-105	COMPUTER, LAPTOP	VAIO SRX99	3404912	SONY	CHICAGO COMPUTER SUPPLY	4500489457	3/18/2003	$1,673.00
41-105	COMPUTER, LAPTOP	INSPIRON 8500	1C03N21	DELL	DELL	4500491010	4/6/2003	$3,053.00
41-105	COMPUTER, LAPTOP	INSPIRON 8500	1J03N21	DELL	DELL	4500491010	4/6/2003	$3,053.00
41-105	COMPUTER, LAPTOP	INSPIRON 8500	2H03N21	DELL	DELL	4500491010	4/6/2003	$3,053.00
41-105	COMPUTER, LAPTOP	INSPIRON 8500	3L03N21	DELL	DELL	4500491010	4/6/2003	$3,053.00
41-105	COMPUTER, LAPTOP	INSPIRON 8500	6K03N21	DELL	DELL	4500491010	4/6/2003	$3,053.00
41-105	COMPUTER, LAPTOP	INSPIRON 8500	7L03N21	DELL	DELL	4500491010	4/6/2003	$3,053.00
41-105	COMPUTER, LAPTOP	INSPIRON 8500	DL03N21	DELL	DELL	4500491010	4/6/2003	$3,053.00
41-105	COMPUTER, LAPTOP	INSPIRON 8500	FD03N21	DELL	DELL	4500491010	4/6/2003	$3,053.00
41-105	COMPUTER, LAPTOP	INSPIRON 8500	FJ03N21	DELL	DELL	4500491010	4/6/2003	$3,053.00
41-105	COMPUTER, LAPTOP	INSPIRON 8500	JL03N21	DELL	DELL	4500491010	4/6/2003	$3,053.00
41-105	COMPUTER SYSTEM, MICRO	DIMENSION 8300	DVK0S21	DELL	DELL	4500501812	5/7/2003	$4,316.00
41-105	COMPUTER, LAPTOP	INSPIRON 8500	6737T21	DELL	DELL	4500502698	5/14/2003	$3,392.00
41-105	COMPUTER, LAPTOP	INSPIRON 8500	H637T21	DELL	DELL	4500502698	5/14/2003	$3,392.00
41-105	ROBOT, MOBILE	PIONEER 2	AT8DG1800	ACTIVMEDIA ROBOTICS	ACTIVMEDIA ROBOTICS	4500488731	5/16/2003	$6,034.00
41-105	ROBOT, MOBILE	PIONEER 2	AT8DG1801	ACTIVMEDIA ROBOTICS	ACTIVMEDIA ROBOTICS	4500488731	5/16/2003	$6,034.00
41-105	ROBOT, MOBILE	PIONEER 2	AT8DG1802	ACTIVMEDIA ROBOTICS	ACTIVMEDIA ROBOTICS	4500488731	5/16/2003	$6,034.00
41-105	ROBOT, MOBILE	PIONEER 2	AT8DG1803	ACTIVMEDIA ROBOTICS	ACTIVMEDIA ROBOTICS	4500488731	5/16/2003	$6,033.00
41-105	ROBOT, MOBILE	PIONEER 2	AT8DG1804	ACTIVMEDIA ROBOTICS	ACTIVMEDIA ROBOTICS	4500488731	5/16/2003	$6,033.00
41-105	ROBOT, MOBILE	PIONEER 2	AT8DG1805	ACTIVMEDIA ROBOTICS	ACTIVMEDIA ROBOTICS	4500488731	5/16/2003	$6,033.00
41-105	ROBOT, MOBILE	PIONEER 2	AT8DG1806	ACTIVMEDIA ROBOTICS	ACTIVMEDIA ROBOTICS	4500488731	5/16/2003	$6,033.00
41-105	ROBOT, MOBILE	PIONEER 2	AT8DG1807	ACTIVMEDIA ROBOTICS	ACTIVMEDIA ROBOTICS	4500488731	5/16/2003	$6,033.00
41-105	SERVER, EDP	PICCOLO AVIONICS	153	CLOUD CAP TECH	CLOUD CAP TECHNOLOGY	4500501072	5/22/2003	$6,011.00
41-105	TRAILER	S612SA30	48BTE12174B034043	SOUTHWEST	ATLANTIC COAST TRAILER	4500514732	6/18/2003	$3,630.00
41-109	AIRCRAFT, MODEL	TOWER TRAINER GOARF		MIT	MIT	102010492	11/3/2003	$17,332.00
41-109	AIRCRAFT, MODEL	TOWER TRAINER GOARF		MIT	MIT	102010492	11/3/2003	$17,331.00
41-109	AIRCRAFT, MODEL	TOWER TRAINER GOARF		MIT	MIT	102010492	11/3/2003	$17,331.00
41-109	AIRCRAFT, MODEL	TOWER TRAINER GOARF		MIT	MIT	102010492	11/3/2003	$17,332.00
41-109	AIRCRAFT, MODEL	TOWER TRAINER GOARF		MIT	MIT	102010492	11/3/2003	$17,332.00
41-109	AIRCRAFT, MODEL	TOWER TRAINER GOARF		MIT	MIT	102010492	11/3/2003	$17,332.00
41-109	AIRCRAFT, MODEL	TOWER TRAINER GOARF		MIT	MIT	102010492	11/3/2003	$17,332.00
41-109	AIRCRAFT, MODEL	TOWER TRAINER GOARF		MIT	MIT	102010492	11/3/2003	$17,332.00
41-109	AIRCRAFT, MODEL	TOWER TRAINER GOARF		MIT	MIT	102010492	11/3/2003	$17,332.00
41-109	AIRCRAFT, MODEL	TOWER TRAINER GOARF		MIT	MIT	102010492	11/3/2003	$17,332.00
41-109	AIRCRAFT, MODEL	TOWER TRAINER GOARF		MIT	MIT	102010492	11/3/2003	$17,332.00
	TOTAL COSTS							**$334,717.00**